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**Thermal analysis of horizontal earth-air heat exchangers in a subtropical climate: An experimental study**

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# Thermal analysis of horizontal earth-air heat exchangers in a subtropical climate: An experimental study

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The earth-air heat exchanger (EHX) has a promising potential to passively save the energy consumption of traditional air conditioning systems while maintaining a high degree of indoor comfort. The use of EHX systems for air conditioning in commercial and industrial settings offers several environmental benefits and is capable of operating in both standalone and hybrid modes. This study tests the performance and effectiveness of an EHX design in a sandy soil area in Baghdad, Iraq. The area has a climate of the subtropical semi-humid type. Ambient air temperatures and soil temperatures were recorded throughout the months of 2021. During the months of January and June, the temperatures of the inlet and outflow air at varying air velocities were monitored concurrently in 10-min increments at each location. Further numerical and thermodynamical analyses of the measurements were conducted to reveal the influencing performance parameters. The highest temperature rises of air between the input and exit sections were determined as 12.3°C (January) and 17.2°C (June). It is found that the maximum values of effectiveness are 0.80 and 0.81, while coefficients of performance are 1.6 and 1.8 for January and June, respectively. It is also found that the EHX shows good functionality and effectiveness, with potential energy savings for equipment for cooling and heating under different weather conditions.

## KEYWORDS

geothermal energy, sandy soil, earth-air heat exchangers, subtropical climate conditions, thermal, analyses

## Introduction

Nowadays, the strength of a country is essentially determined by the extent to which it can get a diverse range of energy sources. Otherwise, the large demand for cooling in developing countries where there is no reliable electricity supply and the electricity consumption on the air conditioning systems increased tremendously. As a source of energy, the earth's tremendous energy storage may be used as a heat sink or source during the summer and winter seasons. Due to the high thermal storage, a time shift between the earth's surface and the soil temperature with the depth can be observed. Moreover, geothermal energy comes as a promising source due to its high availability and more even distribution in nature. Therefore, at a certain depth, the soil temperature is higher than the ambient temperature in the winter and lower in the summer (Pfafferott and Santamouris, 2007). It is noted that soil can be employed as an energy supply by applying earth heat exchangers (EHX) for purposes of ventilation and air-conditioning. EHX is a kind of thermal heat exchanger that can operate with thermal source energy such as geothermal energy. A basic EHX consists of pipes, which are networks buried at a certain depth under the earth's surface (Bulut et al., 2015a).

Moreover, EHX is one of the solutions to the problem of energy crisis in comparison with the conventional vapor-compression system. This machine has a low manufacturing cost, long operating life, and has no moving parts, which makes it silent with cheap maintenance. In my country, Iraq, about two-thirds of the electricity may be consumed for air-conditioning in buildings, which results in a shortage of electricity, therefore, the development of an air conditioning technology with the concept of energy saving and environmental protection is considered to be very important. Several theoretical and technological breakthroughs have been made in the field of EHXs to better explore their employment in heating and cooling applications (Kasim et al., 2013; Atwan et al., 2016; Alhosainy and Aljubury, 2019). The EHXs also receive other benefits when they are coupled with ground-coupled heat pumps, such as protection against dust accumulation, Sun insolation, windstorms, and air infiltration (Esen et al., 2006; Esen et al., 2007a; Esen et al., 2007b; Esen et al., 2007c; Esen et al., 2008a; Esen et al., 2008b; Balbay and Esen, 2013; Esen and Yuksel, 2013; Esen et al., 2017). The functionality of EHX systems was assessed experimentally in different areas and climates around the globe. Benrachi et al. (Benrachi et al., 2017) studied the relevance of EHX application in some Algerian arid areas, and reported that the soil temperature ranged between 26°C at depth of 6 m and 22.2°C at depth of 5 m for cities of ADRAR and EL-OUED, respectively. Mongkon et al. (Mongkon et al., 2014) tested a horizontal EHX system in the tropical climate of Thailand to explore the impact of the tube diameter and air velocity on maximizing the coefficient of performance. They found that the coefficient of performance is better with increasing pipe diameter and air velocity, and this should be considered a routine case for

cooling/heating cycles when heat exchange occurs at a higher rate. More studies (Muehleisen, 2012; Bisioniya et al., 2014; Bulut et al., 2015b; Bisioniya, 2015; Chiesa, 2017) investigated through field tests and numerical simulation the effect of different designs of EXH to increase thermal performance, effectiveness, and efficiency. For instance, Chiesa (2017) assessed the use of precise tools and methods for calculating the performance of the required EXH. Furthermore, he suggested a methodology that gives a primary idea of the climate-related best EXH performance. Liu et al. (2017) studied the thermal performance of EXH in hot summer and cold winter where they measured different parameters such as soil temperature, inlet and outlet air temperatures. They demonstrated that at a distance of 20 m, the inlet air temperature approaches the soil temperature, and the COP and Q decreased with increasing inlet air temperature but increased with increasing pipe length. Literature also reported data for the EXH at different design configurations (Jakhar et al., 2015; Jakhar et al., 2016; Hassoon and Ali, 2021). Rouag et al. (2018) studied the thermal design of an EXH using a new developed semi-analytical method with soil temperature distribution in hot and dry climates. They proved that the thermal performance of their system tends to decrease along with the duration of continuous operation. Also, they linked the thermal performance to several parameters, such as the diameter of the pipe, the soil's ability to move heat, and the diameter of EXH pipes. Mironov et al. (2016) proposed modeling of a horizontal ground heat exchanger that describes the rate of heat transfer between the designed heat exchanger and the soil. Using this model, the results reveal that heat transport rates rapidly decrease when the spacing between pipelines is less than 2 m. Moreover, the developed model can be employed to design a horizontal heat exchanger with optimum operating capability. An 18,000 BTU/hr tube in tube air heat exchanger had been designed and tested under local climate conditions and soil properties of Iran. The results showed that a significant saving in energy consumption and COP of 2.57 was obtained. Knowing soil temperature at a different depth, the ambient air temperature, and solar radiation are important parameters for the design of air heat exchangers (Yari et al., 2005). Singh and Sharma (2017a) presented a numerical analysis of soil temperature. The diurnal temperature variation for the hottest and coldest days and the annual variation for the year 2016 have been computed. Diurnal temperature variation is found up to 0.4 m depth of soil, whereas annual temperature variation is up to a depth of 4 m. An integrated system comprising a solar chimney with an EHX was presented by Maerefat and Haghghi (2010). Theoretical analyses of this study had been introduced for investigating the performance of the proposed system. Without any electricity needed, the results shows that this system has the potential to provide comfortable air conditioning for a long period during the daytime.

An air-to-earth heat exchanger under a transient condition in cooling mode was described and tested at the University of

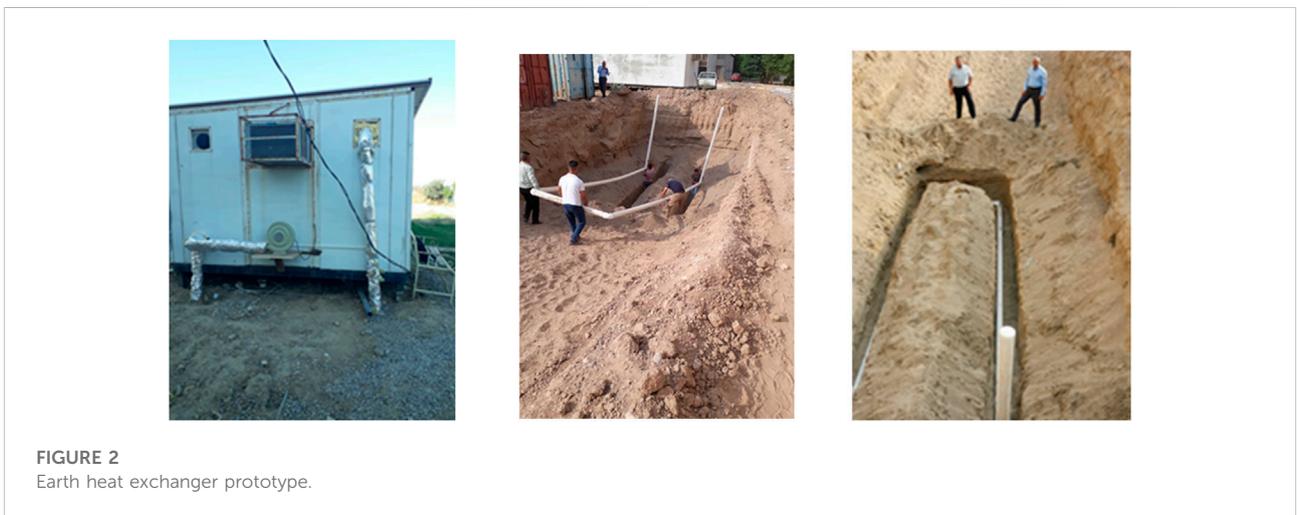
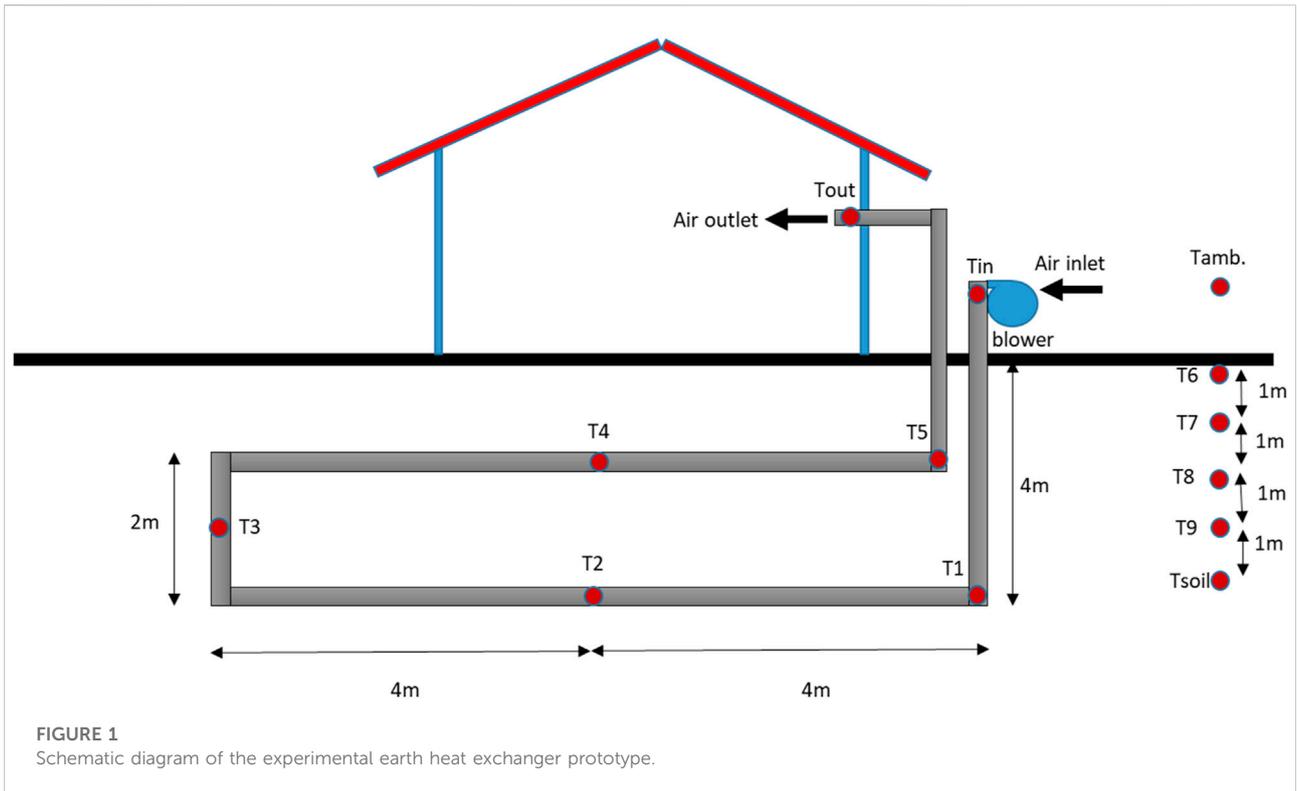
Biskra, Algeria by Belloufi et al. (Belloufi et al., 2017) The performance of the system was analyzed for continuous operation of 71 h based on a prototype of a PVC pipe of 53.16 m long and 110 mm diameter buried at 3 m depth. The experimental results proved that there is no significant effect on the outlet air temperature and thus on the EHE performances during all the continued operations. Besides this finding, a good agreement between their developed model along with the measured temperature has been achieved. The studies on the EHXs are focused on improving thermal performance, which can technically and economically be a serious alternative to conventional systems. Benhammoua and Draouib (2015) applied a transient one-dimensional numerical model for studying the thermal performance of an EHX for summer cooling under the Algerian Sahara conditions. The model is designed for a buried PVC pipe in the ground. The influence of geometrical and dynamical parameters on the thermal performance of EHX is discussed for all experiment phases. The model results showed that the drop in outlet air temperature is higher than the inlet air temperature and is smaller for the longer pipe, and the thermal performance in transient conditions is approached the steady state condition during a short time. The simulation work has been extensively presented in the literature. Most of these studies were aiming at evaluating the performance and studying its dependency on other system parameters (Hollmuller and Lachal, 2001; Tiwari et al., 2014), soil temperature (Singh and Sharma, 2017b), and the exergy efficiency of the whole EAHE (Hepbasli, 2013). A study of the effects of operating parameters on the performance of an earth-air-pipe heat exchanger during the winter season is presented by Bansal et al. (2009). The parameters tested are pipe materials and air velocity with a 34.32 m length pipe. The experimental results have illustrated the ability of the employed system to achieve heating in the range of 4.1–4.8 °C for the flow velocities of 2–5 m/s. Using different materials such as steel and PVC pipes has not affected the performance of the system, on the contrary, air velocity showed a great impact. Later, the same team (Bansal et al., 2010) investigated the performance of an earth heat exchanger during summer cooling. They got a cooling lift temperature of 8.0–12.7 °C and COP of 1.9–2.9 for the flow velocities of 2–5 m/s, higher than in the case of winter heating. A significant decrease in inlet and outlet temperatures was observed, which indicates that the system is efficient. Moreover, these experiments reveal the system is competitive with conventional vapor compression. Greco and Masselli (2020) investigated the thermal performance optimization of a horizontal Earth-Air Heat Exchanger. They reported that the thermal performance increases with the length until the limited distance is attained. A sensibility analysis was executed, by changing the pipe diameter with air velocity affecting the thermal performance of the EAHX. Moreover, they advised the designed pipe with a smaller diameter and low air velocity to obtain closer air outlet temperature to the soil temperature.

Mathur et al. (2017) provided experimental results where a design of spiral heat exchanger buried at a depth of 3 m was used with a 60-m pipe length, a diameter of 0.1 m, and a 1-m distance among the spirals. The results obtained revealed that the coefficient of performance for a spiral configuration is 6.24 in the cooling season and 2.11 in the heating season. Sehli et al. (2012) studied the variation of outlet air temperature with tube form factor, L/D, for an EHX buried at depth of 4 m in the Algerian arid climate under the condition of hot mode. They proved that the outlet air temperature decreases the form factor increases because a longer tube provides a longer residence time for the air inside the pipe enhancing the heat exchange rate. Also, they advised employing low values of Reynolds number where according to their calculations the best value of the form factor was 250.

As per the literature survey above, several attempts have been made by researchers to test the applicability of EHX systems under diverse climatic conditions. However, the applicability verification of EHX systems under very hot subtropical climate conditions, such as that of Iraq, is hard to find. The major phenomenon unique to such a climatic zone is the high-temperature difference between summer and winter, which exceeds 40°C, whereas the previous research has addressed relatively lower temperature differences. Furthermore, the previous research focused mostly on the performance during the cooling mode rather than the heating mode. This study aims to fill in the research gaps identified above by conducting full-scale experimental work in a field setting to explore the effects of the soil and the surrounding temperatures on the performance of earth-heat exchangers running with open-air circulation modes. A parametric analysis was performed to determine the impact of pipe length and air flow rate on the effectiveness of the system. The responsiveness of the designed EHX system to the seasonal changes in atmospheric and subsurface temperatures during the winter and summer seasons was also investigated to identify the heating and cooling potentials of the proposed system. These would be useful for highlighting the adaptation strategies for EHX systems in sandy soil area settings and hot subtropical climatic conditions.

## System description

Figure 1 shows a schematic of the experimental earth heat exchanger prototype. The prototype is designed to test various operating air conditions in the summer and winter seasons. The whole system is consisting of a blower (300 W) and two PVC pipes with 0.1 m-diameter and 0.005 m-thickness. The length of each pipe was 8 m and both pipes were tied in series by a pipe of 2 m. The total length of the buried pipe was 18 m which was entombed at a depth of 4 m in the flat ground with sandy soil at the back area of Al-Khwarizmi engineering college, Iraq. The open end of each buried pipe was connected through a vertical



pipe of 4 m to a centrifugal blower which was fixed at the beginning of one open end. The velocity of the ambient air can be controlled by changing a gate installed at the entrance air inlet of the blower. The air outlet was pushed to a caravan which was installed for monitoring air conditions results.

For ambient air, two main parameters were measured during the experiment: temperature and air velocity. Along the length of the buried pipe, seven thermocouples (type K) were inserted at a

constant interval to measure the temperature of inlet and outlet air ( $T_{in}$ ,  $T_1$ ,  $T_2$ ,  $T_3$ ,  $T_4$ ,  $T_5$ ,  $T_{out}$ ). Another set of five thermocouples was used in the soil to measure the temperature of the soil at different levels ( $T_6$ ,  $T_7$ ,  $T_8$ ,  $T_9$ ,  $T_{soil}$ ). All thermocouples were connected to a data logger of 32 channels type CKT4000 series multi-channel temperature recorder uses 32-bit high-speed CPU for data processing and recorded every 60 s. Pressure drop was not measured to focus on

the estimation of the thermal performance of the heat exchanger. The data measurements were taken every 24 h. A computer was used to collect and process the measurement data acquired by the data logger. The air speeds were measured by a vane type of anemometer at the outlet of the pipe and controlled manually. The different stages of the system installation are shown in [Figure 2](#). The unburied part of the pipe was thermally isolated from the surface of the ground until it was connected to the caravan.

## Analysis method

The effectiveness of the system can be estimated by dividing its actual temperature difference by the maximum temperature difference, as follows:

$$\varepsilon = (T_{in} - T_{out}) / (T_{in} - T_{soil}) \quad (1)$$

COP of the system is investigated by calculating its heating capacity ( $q$ ) using the following equation:

$$q = m \cdot C_p \cdot \Delta T \quad (2)$$

where.

$m$  = the mass flow rate of air in kg/s.

$C_p$  = the specific heat of the air in kJ/kg K and.

$\Delta T$  = the difference between inlet and outlet air temperature.

Effectiveness can be formulated as shown in [Eq. 1](#):

$$COP = q/W \quad (3)$$

where  $W$  (watt) is the power electricity of the blower.

The relative humidity (RH) of the air has an impact on the level of thermal comfort that can be achieved indoors during the summer mode. As a result, it is essential to parameterize its influence to prevent the air from condensing in the EHX pipes. For instance, if the atmospheric air that enters the system has a dew-point temperature lower than the temperature of the soil, then the air that passes through the buried underground pipes will become undesirably moist ([Lindblom and Nordell, 2006](#)). In this work, the dew point of the air temperature during the summer mode was measured to be 11.3°C at the minimum conditions of 48°C and RH of 12% of the atmospheric air entering the system. This dew-point temperature is higher than the soil temperature. Therefore, there was no water vapor condensation from the air entering the system.

## Results and discussion

In order to build and apply the earth heat-exchanger systems in hot summer and cold winter seasons, it is critical to have a thorough understanding of their model designs and operating conditions. This section describes how the possible changes in

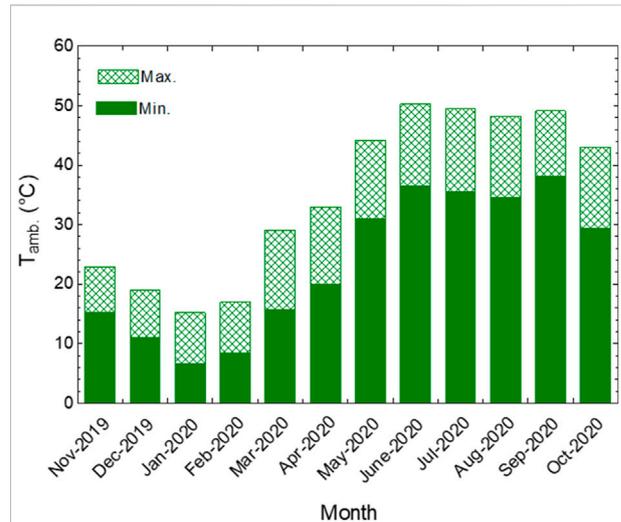


FIGURE 3  
Variation of the ambient temperature with time.

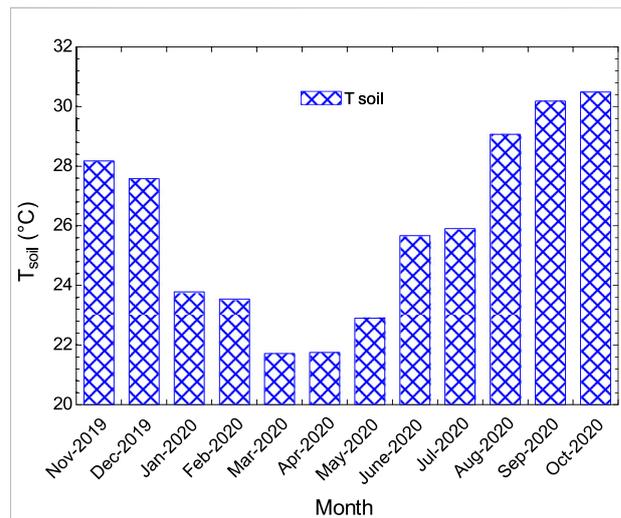
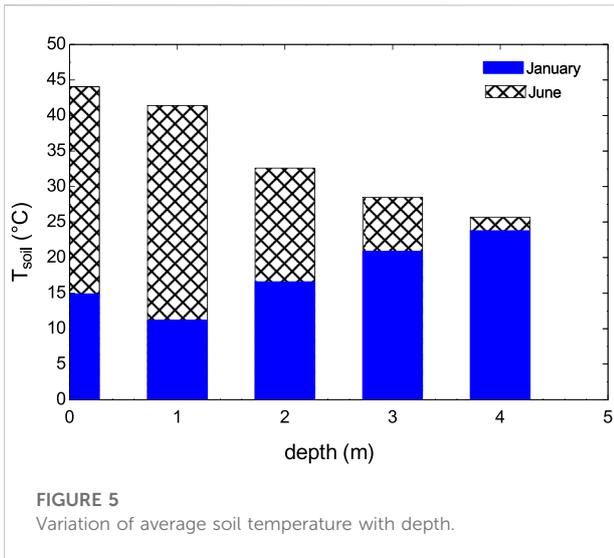


FIGURE 4  
Variation of the soil temperature with time.

subterranean soil temperature, outside air temperature, and inlet air velocity affect the thermal performance of a building's underground soil heater.

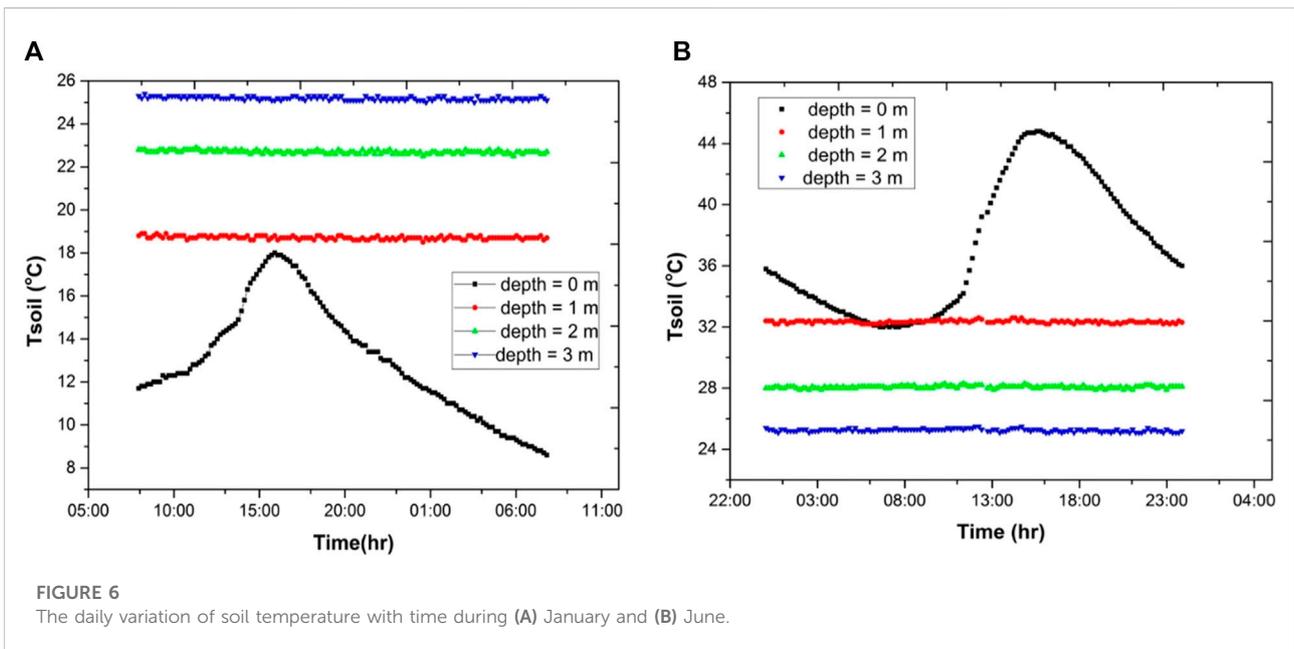
[Figure 3](#) shows the change of the ambient temperature along with each month of the year under the climatic conditions of Iraq. As can be seen, the ambient temperature ranges from 6.6 to 50.3°C which indicated a significant difference in air temperature. Moreover, the air temperature for the hottest and coolest months was observed in June and January, respectively. [Figure 4](#) shows the change of the soil temperature at the depth of 4 m along with



the different months of the year. The lowest soil temperature was recorded in March at 21.71°C which corresponds to maximum and minimum ambient temperatures of 29.1 and 15.7°C, respectively. While the highest soil temperature was observed in October at 30.5°C, with the ambient temperature variations ranging between 43 and 29.4°C. It is an unexpected state that how the variation of the soil temperatures is not incompatible with ambient temperatures. For example, the soil temperature in March was 6°C higher than the minimum soil temperature while in October was higher by 1.1°C. This significant difference can be attributed to the moisture content of the soil in March being higher than in October.

Corresponding to a temperature greater than the surrounding temperature, the average soil temperature at different depths has been measured and shown in Figure 5. It can be seen from the figure that as the depth of the soil grows, the soil temperature rises in January and declines in June. For January month the ground temperatures at 0 m, 1 m, 2 m, 3 m, and 4 m were 14.9, 11.2, 16.6, 20.9, and 23.8°C respectively. It can be noted that the soil temperature increases in the range of 3–4°C at each meter depth. For June month the ground temperatures at 0 m, 1 m, 2 m, 3 m, and 4 m were recorded at 44.1, 41.4, 32.6, 28.5, and 25.7°C respectively. Compared with the soil temperature in June month, January month showed a significant difference in temperature at depth of 1 m, which is lower than at 0 and 2 m. This can be attributed to the moisture content in the soil at 1 m being still a little higher than other nearby layers. At 4 m depth, the soil temperature in January month shows the closest value to that in June month.

When the depth increases, the difference between the soil temperatures for January and June decreases, and it is at a rate of 24–25, which indicates that the soil at this age is suitable for heating and cooling purposes. Figures 6A,B depicts the daily variation of soil temperatures at different depth during the January and June months. It can be seen that the soil temperature is still constant after the depth of 1 m for both January and June. It may be concluded that the used soil is with a low thermal conductivity property. Moreover, poor thermal diffusivity may be another reason for keeping the soil at a constant temperature at different depths. The variation of temperatures of soil, inlet air, outlet air and ambient with time is given during January and June months in Figures 7A,B. There is a significant difference between the ambient



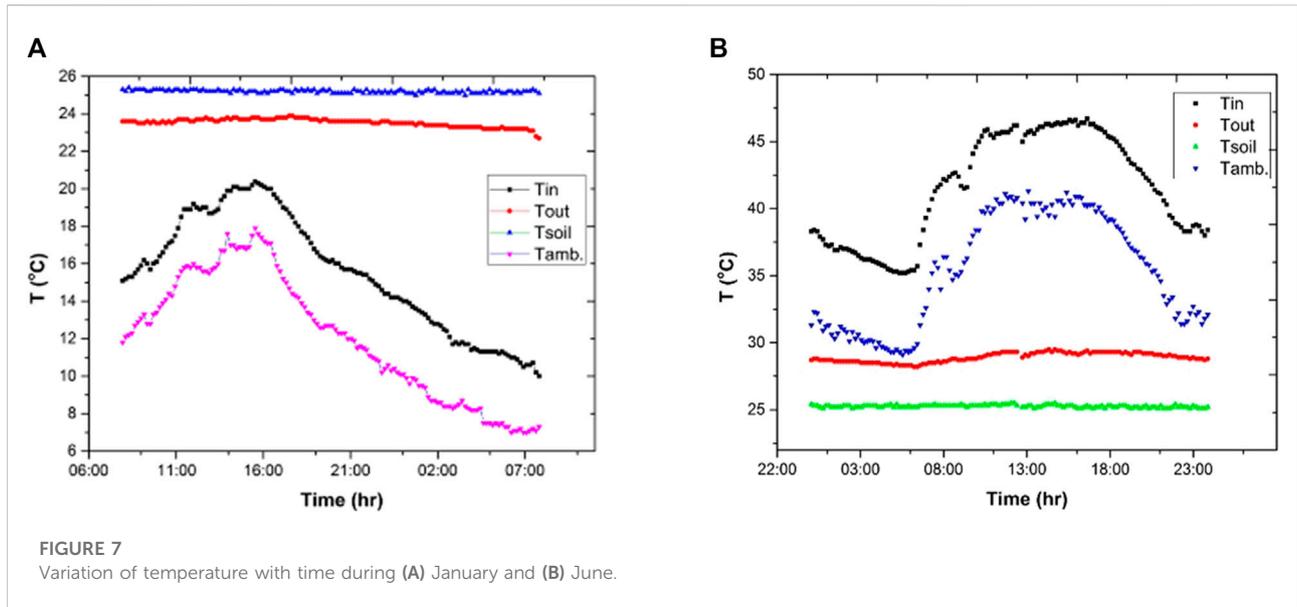


FIGURE 7 Variation of temperature with time during (A) January and (B) June.

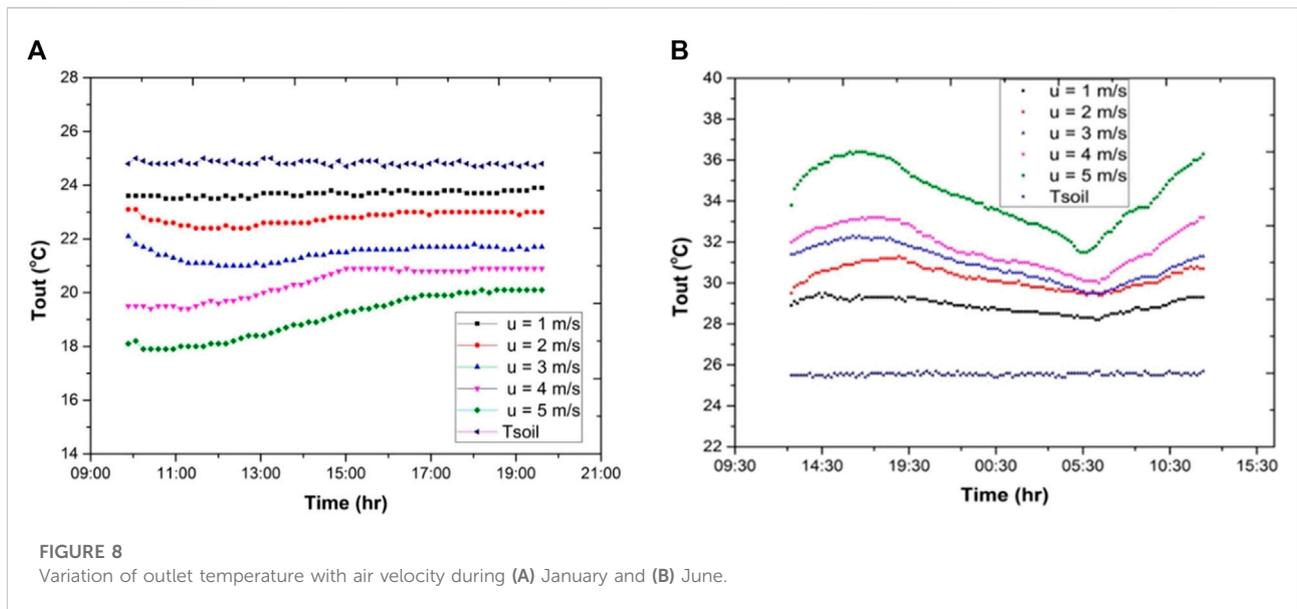
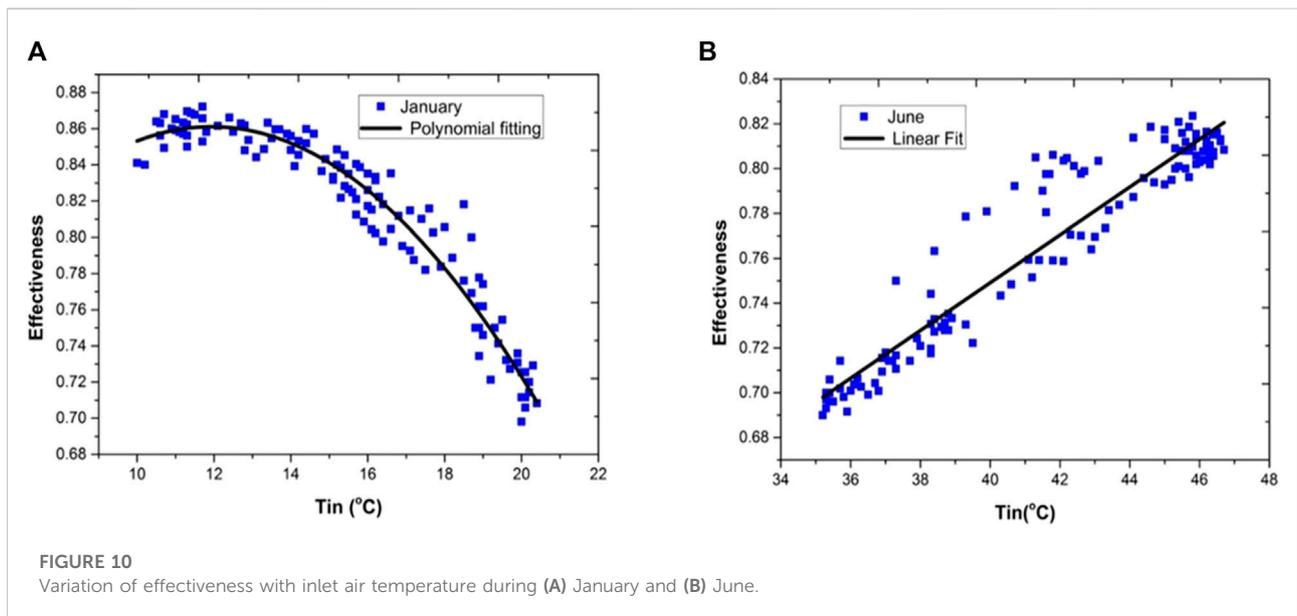
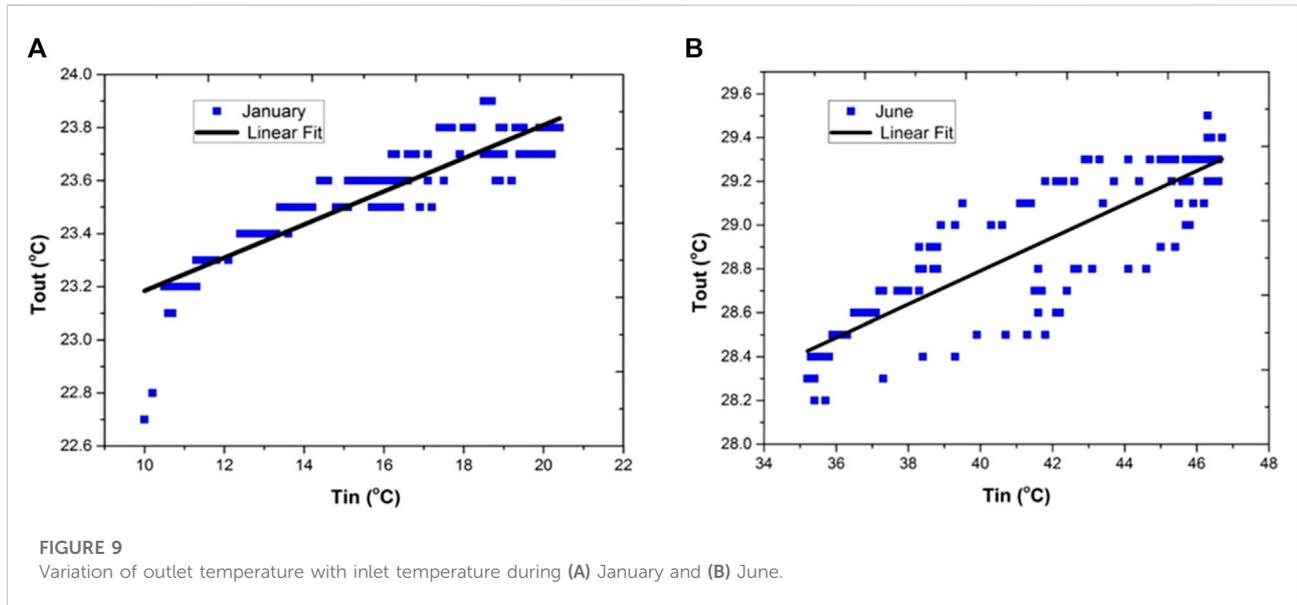


FIGURE 8 Variation of outlet temperature with air velocity during (A) January and (B) June.

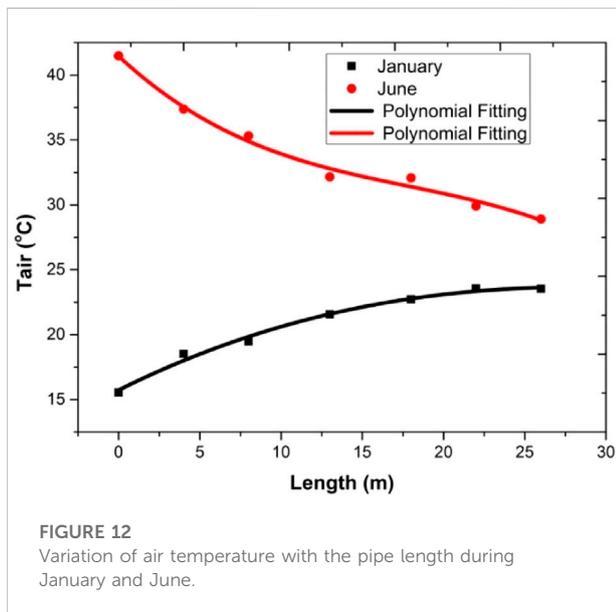
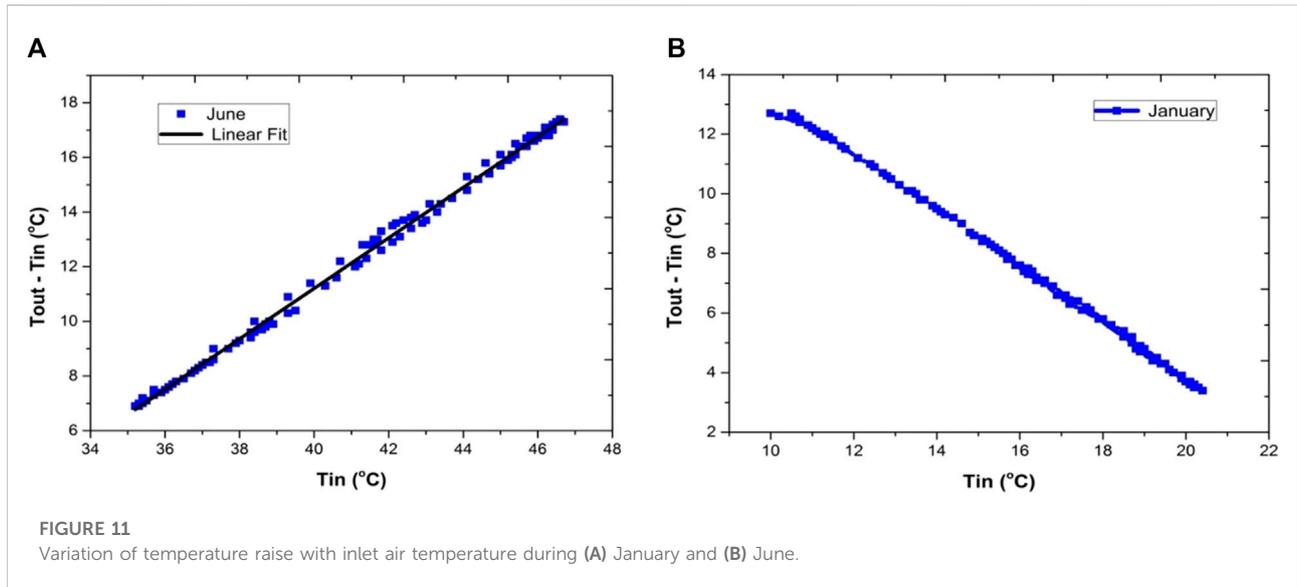
and inlet air temperatures which can be attributed to the generated heat from the friction of air with the blower impeller. Also, it can be noted that the difference in temperatures of soil and the air outlet is higher during June than during January indicating that the system has a higher cooling potential than the heating potential. While the ambient air temperature varies during the day, the outlet air and soil temperatures keep nearly constant, this means that the heating performance of earth-air heat exchangers (EAHX) was stable in this experimental period.

The variation of the outlet air temperature under different air velocities is shown in Figures 8A,B. As seen, when the air velocity is increased, the outlet air temperature lowers during January and increases during June, respectively. It can be noticed that the outlet air temperature virtually maintains a constant in January while swings in June. This indicates that the performance of this prototype during the heating mode was more stable than that of the cooling mode. The rates of rising in output air temperature among the five intake velocity variations are statistically substantially different. The maximum rate occurs when the



intake air velocity is 1 m/s, and the lowest rate occurs when the inlet air velocity is 5 m/s. The inlet air velocity has the greatest influence on the rate. In fact, practically all of the outlet air temperatures increase or drop at or near the soil temperature at a depth of 4 m down, which is a significant increase or reduction. This implies that the heat transport rate between the surrounding air and the soil has been sufficient at the depth in question. The use of such a heat exchanger has the potential to keep the temperature close to the comfort level without the use of air-conditioning. Monitoring of this system has shown that the soil was very effective at heating and cooling the ambient air.

Figures 9A,B illustrate the relationship between the air output temperature and the input temperature. In both winter and summer, we noticed that when the temperature of the air entering the system increases, the temperature of the air exiting the system also increases. Also, it can be seen that temperatures in June were more fluctuating than temperatures in January. These results are consistent with those observed in the work of Chiesa et al. (Chiesa et al., 2014). Figures 10A,B show the change of effectiveness with inlet air temperatures. There is a significant difference in the behavior of effectiveness in January month, curve shape, and in June month, a linear relationship which



causes the effectiveness in January higher than in June. This state can be attributed to the properties of the soil, particularly thermal diffusivity, which indicates that the heat transfer rate from the soil to the pipe in winter is higher than from the air to the soil in summer. That's why the difference between inlet and outlet air temperature is less in June than in January (Figure 11). It became clear that this system works more efficiently in summer than in winter, and as the results proved, the heat potential is transferred better than the cooling potential, which becomes a crucial characteristic of this system. Figure 12 shows the change of air temperature along the length of the pipe under an air

velocity of 1 m/s. The change in air temperature is quicker for the first 18 m of the pipe and it becomes small at the rest of the pipe. This is because of the fact that as the airflow upward from the location T5 to the surface of the ground (4 m), the soil temperature affected the air temperature in a reverse process.

Moreover, the change in air temperature at the vertical section of the pipe (i.e., 0–4 m) is the biggest due to the temperature difference between the soil and air being the highest, and thereby the heat transfer rate in this segment is the highest too. In addition, the increase in air temperature rates is significantly different among all the thermocouples. Although the inlet and outlet temperatures are different, the outlet air temperatures are still not close to the soil temperature indicating that the used 18 m of length pipe is not sufficient to exchange heat between the soil and the surrounding air.

Figure 13 shows the change of effectiveness under the influence of air velocity during January and June month. As seen in Figure 13, the effectiveness decreased along with the increase in air velocity. When the air velocity is 1 m/s, the effectiveness is the highest at 0.8 and 0.82 while the lowest effectiveness of 0.21 and 0.19 are recorded at the air velocity of 4 m/s and 5 m/s in January and June months respectively. It can be seen that the effectiveness decreases along with time and reaches the minimum values at 15:00 for January month and at 5:30 for June month, after this time, it increases again.

The statistical values for parameters tested in January and June are shown in Tables 1 and 2. As can be seen, the average COP values are low for both low and high air velocity. Higher velocity results in a lower average effectiveness of (0.6) in January and (0.46) in June. This occurs because the amount of time available for air to remain in the pipe is shorter. The greatest coefficient of performance (COP) was recorded is 1.6 at a velocity of 5 m/s in January and 1.8 in June. Although the temperatures

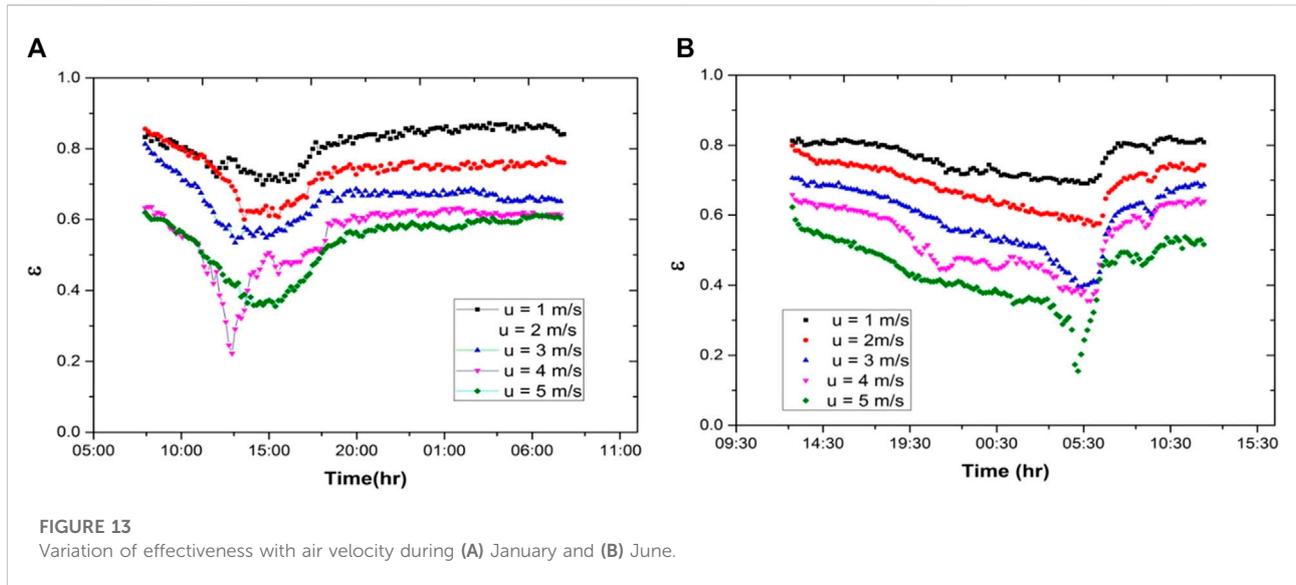


FIGURE 13 Variation of effectiveness with air velocity during (A) January and (B) June.

TABLE 1 Computed parameters at different experimental temperatures during January.

Air velocity	Statistics	T <sub>in</sub>	T <sub>out</sub>	T <sub>soil</sub>	Effectiveness	Power	q	COP	ΔT
m /s		°C	°C	°C		W	W		°C
1	Max	20.4	23.9	25.4	0.7	300	31	0.1	3.5
	Min	15.1	23.5	25.1	0.8	300	74	0.2	8.4
	Avg	18.1	23.7	25.2	0.8	300	49	0.2	5.6
2	Max	19.7	23.1	25.3	0.6	300	60	0.2	3.4
	Min	10.0	22.3	24.9	0.8	300	217	0.7	12.3
	Avg	15.4	22.7	25.1	0.7	300	129	0.4	7.3
3	Max	17.7	22.1	25.2	0.6	300	116	0.4	4.4
	Min	8.6	19.8	24.8	0.7	300	296	0.1	11.2
	Avg	12.8	20.9	24.9	0.7	300	214	0.7	8.1
4	Max	19.6	21.0	25.1	0.3	300	49	0.2	1.4
	Min	7.2	18.1	24.8	0.6	300	385	1.3	10.9
	Avg	7.2	18.1	24.8	0.6	300	385	1.3	10.9
5	Max	17.2	20.3	25.0	0.4	300	137	0.5	3.1
	Min	7.1	17.9	24.7	0.6	300	476	1.6	10.8
	Avg	12.0	19.0	24.8	0.6	300	311	1.0	7.1
	Max	20.4	23.9	25.4	0.8	300	476	1.6	12.3
	Min	7.1	17.9	24.7	0.3	300	31	0.1	1.4
Avg	13.0	21.1	25.0	0.6	300	202	0.7	7.2	

change during the day and in the month, the maximum temperature difference between inlet and outlet air is estimated as 12.3°C (January) and 17.2°C (June) and the mean difference is found at 7.2 and 9.4°C in the EAHX system. While inlet temperature and air velocity change during the day and the month, the average outlet air temperature change in the range of

(17.9–23.9) °C (January) and in the range of (28.2–36.4) °C (June).

Table 3 compares the results of this study to those of three previous studies carried out by Bulut et al. (2015b), Bisioniya et al. (2014), and Liua et al. (2017). Compared to previous systems, this system exhibits a significant improvement in the temperature

TABLE 2 Computed parameters at different experimental temperatures during June.

Air velocity	Statistics	T <sub>in</sub>	T <sub>out</sub>	T <sub>soil</sub>	Effectiveness	Power	q	COP	ΔT
m /s		°C	°C	°C		W	W		°C
1	Max	46.7	29.5	25.5	0.81	300	152	0.5	17.2
	Min	35.2	25.1	25.1	0.69	300	62	0.2	7.0
	Avg	41.5	25.3	25.3	0.78	300	111	0.4	12.6
2	Max	47.4	31.3	25.6	0.74	300	284	0.9	16.1
	Min	35.1	29.4	25.1	0.57	300	101	0.3	5.7
	Avg	41.8	30.3	25.3	0.70	300	203	0.4	11.5
3	Max	47.1	32.3	25.6	0.69	300	392	1.3	14.8
	Min	32.3	29.5	25.2	0.39	300	74	0.2	2.8
	Avg	39.8	30.9	25.4	0.62	300	235	0.8	8.9
4	Max	47.4	33.3	25.7	0.65	300	497	1.7	14.1
	Min	32.7	30.3	25.3	0.36	300	95	0.3	2.7
	Avg	39.8	31.8	25.5	0.56	300	282	0.9	8.0
5	Max	48.4	36.4	25.7	0.53	300	529	1.8	12.0
	Min	32.7	31.5	25.4	0.16	300	53	0.2	1.2
	Avg	41.8	34.3	25.5	0.46	300	331	1.1	7.5
	Max	48.4	36.4	25.7	0.81	300	529	1.8	17.2
	Min	32.3	28.2	25.1	0.16	300	53	0.2	1.2
Avg	40.6	31.3	25.4	0.57	300	234	0.8	9.4	

TABLE 3 Results of this work with the results of similar works.

Ref	T <sub>in</sub> /T <sub>out</sub>	Air velocity (m/s)	ε	COP	Heating load (W)	Cooling load (W)	Soil temperature (°C)
Present work	47.7/31.3	2	0.81	1.8	426	529	25
Bulut et al. (2015b)	42.2/29.8	3.1	0.79	0.236	-	776	23.7
Bisoniya et al. (2014)	40.4/27.5	2	-	3.5	-	-	-
Liu et al. (2017)	14.3/18	1.5	-	2.7	400	-	17.5

difference between the air input and air output. This increase in temperature difference would be attributed to the higher rate of heat exchange inside the EHX pipes. It can also be noted that this EHX design has a lower COP than both of its predecessors. This might be explained by the lower soil temperature, which was influenced by the soil type and surrounding environmental conditions. Regarding the COP results, this system exhibits a higher value of heating load as compared to the one designed by Liu et al. (2017). This is because the greater the difference in temperature increase, the greater the gain in the overall system effectiveness.

## Conclusion

In this work, an EAHE was designed, established and tested in sandy soil in Baghdad. The influence of different variables

including ambient air temperature, soil temperature, and air velocity on the thermal performance (COP) and effectiveness ( $\epsilon$ ) was analyzed during the hottest and coldest months of the year 2020. The outlet temperature decreases along with air velocity and the supply air temperature. COP and effectiveness decrease with air velocity but increase with the inlet air temperature. The COP and  $\epsilon$  of the EAHE during January could reach up to the maximum of 1.8 and 0.81 respectively, when the inlet air temperature is 48.8°C, and decrease to the minimum of 0.2 and 0.16 respectively when the inlet air temperature is 32.3°C. It was concluded that this system can be used effectively to reduce the cooling and heating duties of buildings in hot and cold weather conditions. A significant amount of electrical power can be conserved if it is used instead of conventional air conditioning systems. A further amount of energy consumption can be decreased by combining it with different renewable energy

sources such as wind turbines, solar panels, and biogas to meet its energy demand. Our next work includes experimentally investigating the performance of EAHE under more influencing parameters, such as pipe length, pipe diameter and pipe material. Moreover, mathematical models will be modified to optimize the system's performance under different operation conditions. It is expected that this system will be consecutively applied in different areas in Iraq.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

## Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## References

- Alhosainy, A. H. M., and Aljubury, I. M. A. (2019). Two stage evaporative cooling of residential building using geothermal energy. *jcoeng* 25, 29–44. doi:10.31026/j.eng.2019.04.03
- Atwan, A. F., Kasim, N. K., and Khudhair, W. A. (2016). Effect of geothermal heat pump on carbon dioxide emissions. *Int. J. Sci. Technol. Res.* 5, 175.
- Balbay, A., and Esen, M. (2013). Temperature distributions in pavement and bridge slabs heated by using vertical ground-source heat pump systems. *Acta Sci. Technol.* 35, 677–685. doi:10.4025/actascitechnol.v35i4.15712
- Bansal, V., Misra, R., Agrawal, G. D., and Mathur, J. (2010). Performance analysis of earth-pipe-air heat exchanger for summer cooling. *Energy Build.* 42, 645–648. doi:10.1016/j.enbuild.2009.11.001
- Bansal, V., Misra, R., Agrawal, G. D., and Mathur, J. (2009). Performance analysis of earth-pipe-air heat exchanger for winter heating. *Energy Build.* 41, 1151–1154. doi:10.1016/j.enbuild.2009.05.010
- Belloufi, Y., Brima, A., Zerouali, S., Atmani, R., Aissaoui, F., Rouag, A., et al. (2017). Numerical and experimental investigation on the transient behavior of an earth air heat exchanger in continuous operation mode. *Int. J. Heat Technol.* 35, 279–288. doi:10.18280/ijht.350208
- Benhammou, M., and Draoui, B. (2015). Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings. *Renew. Sustain. Energy Rev.* 44, 348–355. doi:10.1016/j.rser.2014.12.030
- Benrachi, N., Ghemari, N., Ouzzane, M., and Smali, A. (2017). "A numerical study of ground temperature distribution in Algerian arid regions," in *National conference CFD & Tech2016* (CRND-Draria, Alger: CFD & Tech).
- Bisoniya, T. S. (2015). Design of earth-air heat exchanger system. *Geotherm. Energy* 3, 18–10. doi:10.1186/s40517-015-0036-2
- Bisoniya, T. S., Kumar, A., and Baredar, P. (2014). Cooling potential evaluation of earth-air heat exchanger system for summer season. *Int. J. Eng. Tech. Res.* 2, 309–316. doi:10.1177/1744259114542403
- Bulut, H., Demirtaş, Y., Karadağ, R., and Hilali, İ. (2015). "Experimental analysis of an earth tube ventilation system under hot and dry climatic conditions," in *Proceedings of The 8th Mediterranean Congress of Heating Ventilation and Air-Conditioning-Climamed*, September 9–11, 2015 (Juan Les Pins, France: Sobti and Singh Geothermal Energy), 1–8.
- Bulut, H., Karadağ, R., Demirtaş, Y., and Hilali, İ. (2015). "Performance analysis of an earth-air heat exchanger under winter conditions of Şanlıurfa," in *Proceedings*

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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of the 12nd National Sanitary Engineering Congress, Izmir, Turkey (National Sanitary Engineering Congress), Vol. 2, 1789–1804.

Chiesa, G. (2017). Climate-potential of earth-to-air heat exchangers. *Energy Procedia* 122, 517–522. doi:10.1016/j.egypro.2017.07.300

Chiesa, G., Simonetti, M., and Grosso, M. (2014). A 3-field earth-heat-exchange system for a school building in Imola, Italy: Monitoring results. *Renew. energy* 62, 563–570. doi:10.1016/j.renene.2013.08.020

Esen, H., Esen, M., and Ozsolak, O. (2017). Modelling and experimental performance analysis of solar-assisted ground source heat pump system. *J. Exp. Theor. Artif. Intell.* 29, 1–17. doi:10.1080/0952813x.2015.1056242

Esen, H., Inalli, M., and Esen, M. (2007). A techno-economic comparison of ground-coupled and air-coupled heat pump system for space cooling. *Build. Environ.* 42, 1955–1965. doi:10.1016/j.buildenv.2006.04.007

Esen, H., Inalli, M., and Esen, M. (2007). Numerical and experimental analysis of a horizontal ground-coupled heat pump system. *Build. Environ.* 42, 1126–1134. doi:10.1016/j.buildenv.2005.11.027

Esen, H., Inalli, M., Esen, M., and Pihtili, K. (2007). Energy and exergy analysis of a ground-coupled heat pump system with two horizontal ground heat exchangers. *Build. Environ.* 42, 3606–3615. doi:10.1016/j.buildenv.2006.10.014

Esen, H., Inalli, M., and Esen, M. (2006). Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. *Energy Convers. Manag.* 47, 1281–1297. doi:10.1016/j.enconman.2005.06.024

Esen, H., Inalli, M., Sengur, A., and Esen, M. (2008). Artificial neural networks and adaptive neuro-fuzzy assessments for ground-coupled heat pump system. *Energy Build.* 40, 1074–1083. doi:10.1016/j.enbuild.2007.10.002

Esen, H., Inalli, M., Sengur, A., and Esen, M. (2008). Modelling a ground-coupled heat pump system using adaptive neuro-fuzzy inference systems. *Int. J. Refrig.* 31, 65–74. doi:10.1016/j.ijrefrig.2007.06.007

Esen, M., and Yuksel, T. (2013). Experimental evaluation of using various renewable energy sources for heating a greenhouse. *Energy Build.* 65, 340–351. doi:10.1016/j.enbuild.2013.06.018

Greco, A., and Masselli, C. (2020). The optimization of the thermal performances of an earth to air heat exchanger for an air conditioning system: A numerical study. *Energies* 13, 6414. doi:10.3390/en13236414

- Hassoon, A. F., and Ali, A. B. (2021). Irregular urban expansion and its effects on air temperature over Baghdad city using remote sensing technique. *eijs*. 62, 2110–2121. doi:10.24996/eijs.2021.62.6.36
- Hepbasli, A. (2013). Low exergy modelling and performance analysis of greenhouses coupled to closed earth-to-air heat exchangers (EAHEs). *Energy Build.* 64, 224–230. doi:10.1016/j.enbuild.2013.05.012
- Hollmuller, P., and Lachal, B. (2001). Cooling and preheating with buried pipe systems: Monitoring, simulation and economic aspects. *Energy Build.* 33, 509–518. doi:10.1016/s0378-7788(00)00105-5
- Jakhar, S., Misra, R., Bansal, V., and Soni, M. (2015). Thermal performance investigation of earth air tunnel heat exchanger coupled with a solar air heating duct for northwestern India. *Energy Build.* 87, 360–369. doi:10.1016/j.enbuild.2014.11.070
- Jakhar, S., Misra, R., Soni, M., and Gakkhar, N. (2016). Parametric simulation and experimental analysis of earth air heat exchanger with solar air heating duct. *Eng. Sci. Technol. Int. J.* 19, 1059–1066. doi:10.1016/j.jestch.2016.01.009
- Kasim, N. K., Ahmed, F. A., and Ala'a, H. S. (2013). "Calculation of underground soil temperature for the installation of ground heat exchange systems in Baghdad," in The 20th scientific conference of college of Education Al-Mustansiriyah University 2013, 24–25 May, 2013 (Iraq - Baghdad: The Seasonal Storage of Thermal Solar Energy in Iraq), 24–25.
- Lindblom, J., and Nordell, B. (2006). Water production by underground condensation of humid air. *Desalination* 189, 248–260. doi:10.1016/j.desal.2005.08.002
- Liu, J., Yu, Z. J., Liu, Z., Qin, D., Zhou, J., and Zhang, G. (2017). Performance analysis of earth-air heat exchangers in hot summer and cold winter areas. *Procedia Eng.* 205, 1672–1677. doi:10.1016/j.proeng.2017.10.342
- Maerefat, M., and Haghghi, A. (2010). Passive cooling of buildings by using integrated earth to air heat exchanger and solar chimney. *Renew. Energy* 35, 2316–2324. doi:10.1016/j.renene.2010.03.003
- Mathur, A., Mathur, S., Agrawal, G., and Mathur, J. (2017). Comparative study of straight and spiral earth air tunnel heat exchanger system operated in cooling and heating modes. *Renew. Energy* 108, 474–487. doi:10.1016/j.renene.2017.03.001
- Mironov, R., Shtern, Y. I., Shtern, M. Y., and Rogachev, M. (2016). A heat transfer model of a horizontal ground heat exchanger. *AIP Conf. Proc. AIP Publ. LLC* 1727, 020015. doi:10.1063/1.4945970
- Mongkon, S., Thepa, S., Namprakai, P., and Pratinthong, N. (2014). Cooling performance assessment of horizontal earth tube system and effect on planting in tropical greenhouse. *Energy Convers. Manag.* 78, 225–236. doi:10.1016/j.enconman.2013.10.076
- Muehleisen, R. T. (2012). Simple design tools for earth-air heat exchangers. *Proc. SimBuild* 5, 723–730. doi:10.13140/2.1.2854.5607
- Pfafferoth, J. (2007). "Ground cooling: Recent progress," in *Advances in passive cooling2007*. Editor M. Santamouris (London: Routledge, Taylor & Francis Group), 38.
- Rouag, A., Benchabane, A., and Mehdid, C-E. (2018). Thermal design of Earth-to-Air Heat Exchanger. Part I a new transient semi-analytical model for determining soil temperature. *J. Clean. Prod.* 182, 538–544. doi:10.1016/j.jclepro.2018.02.089
- Sehli, A., Hasni, A., and Tamali, M. (2012). The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria. *Energy Procedia* 18, 496–506. doi:10.1016/j.egypro.2012.05.061
- Singh, R. K., and Sharma, R. (2017). Simulation of soil temperature variation for geothermal applications. *IJMET* 8, 167–175.
- Singh, R. K., and Sharma, R. V. (2017). Numerical analysis for ground temperature variation. *Geotherm. Energy* 5, 22–10. doi:10.1186/s40517-017-0082-z
- Tiwari, G., Singh, V., Joshi, P., Deo, A., and Gupta, A. (2014). Design of an earth air heat exchanger (EAHE) for climatic condition of Chennai, India. *Open Environ. Sci.* 8, 24–34. doi:10.2174/1876325101408010024
- Yari, M., Javaani, N., Ansari, A., and Moradian, H. (2005). Design and installation of the first geothermal heat pump in Iran. *Proc. World Geotherm. Congr.* 2005, 24–29.